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PROPERTIES OF AMMONIUM SULFATE, AMMONIUM BISULFATE AND SULFUR DIOXIDE SOLUTIONS IN AMMONIA SCRUBBING PROCESSES

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Sulfur Dioxide
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ABSTRACT

The report gives the results of a study that involved the collection of data that should be useful in evaluating pilot plant operation of an ammonia scrubber with an ammonium bisulfate regeneration system. The study determined: (1) the density, pH, and composition of saturated $(NH_4)_2SO_4$ solutions at 50, 65, and 80°C; (2) the effects on density, pH, and composition of NH_4HSO_4 addition to the solutions in (1); and (3) the solubility and the stripping rates of SO_2 in saturated solutions of ammonium sulfate containing ammonium bisulfate at 65°C and 80°C.

The solubility of $(NH_4)_2SO_4$ in water was determined and compared with accepted values: good agreement was found. Addition of NH_4HSO_4 to the saturated solutions lowered the solubility of $(NH_4)_2SO_4$, decreased the pH, and increased the density. The solubility of SO_2 in saturated $(NH_4)_2SO_4$ decreased with increasing temperature and with increasing concentration of NH_4HSO_4. For the system and conditions used in this experiment, SO_2 stripping rates were found to be first order with respect to concentration of SO_2 except when the pH rose above 2.6. The stripping rate is dependent on temperature, NH_4HSO_4 concentration, and almost certainly on sweep gas rate and agitation rate.

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Section I
CONCLUSIONS

For the experimental conditions used:

1. The pH, density, and composition of saturated ammonium sulfate solutions determined at 50, 65, and 80°C are consistent with literature values.[1]

2. Ammonium bisulfate addition to the above solutions lowered $(NH_4)_2SO_4$ solubility, decreased pH, increased density, and lowered SO_2 solubility.

3. The stripping rate of SO_2 from $(NH_4)_2SO_4$ solutions, $-dSO_2/dt$, was found to be a linear function of SO_2 concentration for pH values below 2.6.

Section II

RECOMMENDATIONS

A valuable addition to the accomplishments listed in this report would be an investigation of the effects of agitation and gas flow rate on SO_2 stripping rates. It would be useful to know the effects of these variables on the first order stripping rate constant. Without these data, scale up is difficult. The usefulness of the rate data which are contained in this report is limited to qualitative work only.

Another area requiring investigation is the effect of ammonium bisulfate on the release rates from ammonium sulfite-sulfate solutions. These data would be of great benefit in studying acidifier kinetics in the ammonia scrubbing process.

Section III
INTRODUCTION

Background

The problem of stack gas desulfurization has received much attention in the past few years. As a result, modifications of NH_3 scrubbing of SO_2 with an NH_4HSO_4 regeneration cycle are being investigated. The original work is described in Hixon and Miller patent No. 2,405,747.

This process essentially consists of scrubbing the flue gas stream with an NH_3 and $(NH_4)SO_4$ solution. The scrubber effluent is then acidified with NH_4HSO_4 to release the greater portion of SO_2, stripped of the remaining SO_2 in a stripper, neutralized with NH_3, and crystallized to yield solid $(NH_4)_2SO_4$. The solid $(NH_4)_2SO_4$ is thermally decomposed to yield NH_4HSO_4 and NH_3 which are recycled back into the process (see Figure 1).

The reactions below describe the chemistry of the system.

Scrubber Reactions

$$NH_3 + H_2O + SO_2 \rightarrow NH_4HSO_3$$

$$NH_4HSO_3 + NH_3 \rightarrow (NH_4)_2SO_3$$

$$(NH_4)_2SO_3 + SO_2 + H_2O \rightarrow 2\ NH_4HSO_4$$

Regeneration Reactions

$$(NH_4)_2SO_3 + 2\ NH_4HSO_4 \rightarrow 2(NH_4)_2SO_4 + SO_2\uparrow + H_2O$$

$$NH_4HSO_3 + NH_4HSO_4 \rightarrow (NH_4)_2SO_4 + SO_2\uparrow + H_2O$$

$$(NH_4)_2SO_4 \xrightarrow{\text{Heat}} NH_4HSO_4 + NH_3$$

Objectives

This study will be used as a basis to evaluate the results of the pilot plant operation. In particular, basic SO_2 release rate data are needed to evaluate the effectiveness of the stripper and acidifier.

There were three objectives that this work was to meet in order to satisfy the need of the pilot plant project. First, measurements of the density, pH, and composition of saturated $(NH_4)_2SO_4$ solutions were to be determined at 50, 65, and 80°C. Since the solutions throughout the process would be nearly saturated it is important to know these values. Also some of these data were available in the literature[1] as a check on accuracy of the measurements. Second, the effects of addition of NH_4HSO_4 on density, pH, and composition of these solutions were to be studied. These effects are important in the operation of the acidifier. Finally, the solubility and the stripping rates of SO_2 in saturated solutions of $(NH_4)_2SO_4$ containing incremental amounts of NH_4HSO_4 were to be studied at 65 and 80°C. These data would yield the characteristics of the release of SO_2 in the acidifier and in the stripper.

Section IV

PROCEDURE

Equipment

The reaction vessels in this experiment were 500 and 1000 ml, three-necked, round-bottom flasks. Agitation was supplied by a 6.25 cm. Teflon blade on a 0.95 cm. diameter glass rod powered by a Fisher Dyna Mix. The SO_2 and N_2 gas flow rates were measured by Brooks Rotameters. An Instrumentation Laboratories Model 245 pH meter (with a Beckman 39183 Combination Electrode) was used to measure pH. Density was measured by weighing the sample with a Sartorius analytical balance.

Materials

$(NH_4)_2SO_4$ was obtained from two suppliers: Matheson, Coleman, and Bell and Fisher Scientific. The latter was used for all SO_2 absorption and stripping rates; the former was used for the 50 and 65°C solubility data only. A comparison made between the salts failed to show a difference. The comparison results can be seen in Figures 2 through 5. The 65°C data in these figures were determined using each salt. Material from Matheson, Coleman, and Bell was used in procedure A and from Fisher Scientific in procedure B. NH_4HSO_4 was purchased from Fisher Scientific. N_2 and pure anhydrous SO_2 were supplied by Matheson Gas Products. Appendix A is a lot analysis of the solid chemicals used in these experiments.

Experimental Methods

The properties of $(NH_4)_2SO_4$ and NH_4HSO_4 solutions at 50 and 65°C were determined by a different method than the one used for the 80°C data. The change in procedure resulted from several factors, the most important of which was the inadequacy of the sampling technique used in the original method for temperatures above 65°C. A change in the determination of solution composition was made to increase the accuracy of readings at lower bisulfate concentrations. The change in suppliers of $(NH_4)_2SO_4$ was due to a greater than anticipated usage of the chemical.

For simplicity, procedure A for the 50 and 65°C data will be described in detail; changes made for the 80°C data, procedure B, will follow.

For procedure A (used for 50 and 65°C data), saturated $(NH_4)_2SO_4$ solutions were prepared by placing 400 g of the reagent grade crystals and 320 ml of deoxygenated, deionized water into a three-necked flask. The solution was heated for 2 hours at 95°C and cooled to the desired temperature by adding ice to the bath as needed. After 20 minutes a sample of the solution was withdrawn with a standard 5 ml transfer pipet and drained into a tared vessel. The sample was weighed to determine density and analyzed by a barium perchlorate titration[2] for $SO_4^=$ and the Kjeldal analysis[3] for NH_4. The pH was recorded at the time the sample was taken. The measurements made above were repeated on $(NH_4)_2SO_4$ saturated solutions containing NH_4HSO_4 which had been added incrementally. Twenty minutes was allowed for each portion of bisulfate to dissolve, and complete solution was verified by a non-changing pH response.

For procedure B (used for the 80°C data), an insulated and heated automatic pipet replaced the standard pipet. An NaOH titration using formaldehyde to tie up NH_4^+ ions was used for the $(NH_4)_2SO_4$ determination.[4]

Solubility of SO_2 and the SO_2 stripping rates were determined in procedure B by preparing 1 liter of saturated $(NH_4)_2SO_4$ in the same manner as for procedure A. Pure SO_2 was bubbled into the flask at a rate of 600 cm^3/min through a fritted glass impinger immersed in the solution. Agitation was constant at 200 rpm. In order to take a liquid sample, agitation had to be stopped to allow settling of excess $(NH_4)_2SO_4$ crystals. Thus, for this period gas flow was stopped, and the sample period was not included in the time measurement. Initially, and at each sample period, the pH, composition, and density were measured. The saturated SO_2 solution produced above was then stripped with N_2 gas at 1000 cm^3/min and 200 rpm agitation. Samples were taken and analyzed using procedure B, and SO_2 concentrations were determined iodimetrically.[5]

The effects of NH_4HSO_4 on stripping and solubility of SO_2 were determined by making the same measurements on saturated sulfate solutions containing incremental amounts of NH_4HSO_4.

A discussion of measurement accuracy follows. First the reading on the pH meter was accurate to $\pm$ 0.01 pH unit when tested against known standards. Density measurements were found to be within 0.005 g/ml of the correct value. This deviation was the maximum error found in several determinations of the density of distilled water. The accuracy of the analytical methods for composition was for the most part good. Both of the methods for sulfate and sulfite analysis were found to be within 1% accuracy. The bisulfate analyses were accurate to within 1% except when SO_2 analyses were also performed. In these cases the tests were only accurate to within 10 g/l. This effect is explained in the discussion.

Section V

DISCUSSION

Table 1 contains the properties of saturated $(NH_4)_2SO_4$ solutions. The composition of the solutions agrees to within 1% of the values listed in the literature. Linke and Seidell[1] list the solubility of $(NH_4)_2SO_4$ in weight percent rather than grams per liter. Thus, to compare the Table 1 values with Linke and Seidell values, both the density and the concentration in Table 1 must be used. This situation indicates that the experimental values of both concentration and density are reliable. There is a question, however, as to the reliability of the pH reading. It should be pointed out that all pH's reported are instrument readings: no corrections were made for electrode processes as the correction factor was assumed negligible for the present work. For saturated solutions the pH drifted with time to lower values. Raising the temperature of the solution accelerated the pH drop. Information available from the lot analysis of the chemical indicated that the pH of a 5% solution would be in the range of 5.0 to 6.0 pH units. Freshly made saturated and 5% solutions fell into this pH range, but in both cases pH drifted to lower values according to the time-temperature history of the solution. It is thought that this drop in pH was due to thermal decomposition of $(NH_4)_2SO_4$ to NH_4HSO_4. However, this has not been confirmed because the analysis for NH_4HSO_4 is not sensitive to such low concentrations.

The effects of NH_4HSO_4 addition can be noted from Table 2 and Figures 2-5. Figures 2 and 3 show that the addition of NH_4HSO_4 to saturated $(NH_4)_2SO_4$ solutions lowers the solubility of the latter salt in that solution. Figure 3 shows the data on a constant water basis. The major source of error in these data is the determination of low NH_4HSO_4 concentrations. In the 50 and 65°C data, this error resulted from taking a small difference between two large titrations. The 80°C readings using procedure B should be somewhat more reliable because they were determined by direct titration. The work for 50 and 65°C had already been completed when the analysis in procedure B was initiated.

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A second effect, the pH lowering due to the acid nature of NH_4HSO_4, is shown in Figure 4. The pH lowering is independent of temperature. There are no data in the available literature with which a comparison can be made. The pH reading did not suffer from the same drift as noted above in the pure saturated solutions.

A third effect of NH_4HSO_4 on $(NH_4)_2SO_4$ solutions is the increase in density of the solution with the increase of NH_4HSO_4. It appears from Figure 5 that the density of the saturated solutions is independent of temperature. One explanation of this is that the increase of salt concentration offsets the increase in volume.

Absorption rates for SO_2 in $(NH_4)_2SO_4$ and NH_4HSO_4 solutions were measured to indicate when the solutions were reaching saturation. Thus, the end points of the curves in Figures 6 and 7 show solutions which are approximately saturated in SO_2. Figure 8 shows the decrease of the solubility of SO_2 in solution as the concentration of NH_4HSO_4 increases. Tables 3 through 6 show that the density measurements were unaffected by the concentration of SO_2. Although there is scatter in the data, these tables indicate that concentration of SO_2 has no effect on the concentration of $(NH_4)_2SO_4$ and NH_4HSO_4. The scatter was produced by an analytical method which required taking differences among large numbers when SO_2 was present in the sample. For solutions having no SO_2 (those at zero time in Tables 3 through 6), the $(NH_4)_2SO_4$ and NH_4HSO_4 values were found from direct titrations and are more accurate. Stopping agitation and sweep gas apparently had no effect on the results. The pH did not change during the delay period, indicating no SO_2 evolution, and the experimental stripping curves matched derived, first-order curves closely enough to indicate absences of SO_2 evolution.

The stripping curves in Figures 9 and 10 were analyzed in greater detail than the absorption curves. The instantaneous rate was found at various points on the curves and plotted against the concentration of SO_2

as shown in Figures 11 and 12. The plots, which appear linear except at low concentrations of SO_2 and NH_4HSO_4 (pH values above 2.6), indicate that the first order differential equation below applies:

$$\frac{-dC}{dt} = kC \qquad (1)$$

Where C is concentration of SO_2, g/l; k is the proportionality constant, min^{-1}; and t is time, min. This equation can be integrated to find the concentration at any time which is given by

$$C = C_o e^{-kt} \qquad (2)$$

where C_o is the initial concentration of SO_2, g/l; and e is the natural logarithm base. The rate constant k, which is the slope of the lines in Figures 11 and 12, is listed in Table 7 for various concentrations of NH_4HSO_4 and temperatures. Using equation 2 and obtaining the constants from Figure 8 and Table 7, curves of concentration verus time can be generated and compared with curves in Figures 9 and 10. The agreement is good for all portions of the curve where equation 1 was valid or for portions below a pH of 2.6.

Equation 2 cannot be used in the general case because the dependency of k on temperature, NH_4HSO_4 concentration, sweep gas rate, and agitation is not known.

The deviation in first order behavior above a 2.6 pH is not fully understood. One possible explanation of this phenomenon is that the dissolved SO_2 exists in several forms as described by the following:

$$SO_2 \cdot H_2O \rightleftharpoons H_2SO_3 \rightleftharpoons H^+ + HSO_3^- \rightleftharpoons 2H^+ + SO_3^=$$

According to this hypothesis the mass transfer of SO_2 from the liquid phase to the gas phase is proportional to the concentration of $SO_2 \cdot H_2O$, the driving force. At low pH readings: the H^+ concentration is high,

the equilibrium is shifted to the left, and the SO_2 present is almost exclusively in the hydrated form. Accordingly, the concentration of total SO_2 which is determined analytically is an accurate measure of the true driving force. However, at higher pH values: the H^+ concentration is lower, the equilibrium is shifted to the right, and the SO_2 present is distributed among the several forms. In this case the total SO_2 which is measured analytically is larger than the true driving force, the $SO_2 \cdot H_2O$. It is postulated that if only the $SO_2 \cdot H_2O$ were measured at any time the first order behavior would be observed over the whole pH range.

Section VI

ACKNOWLEDGEMENTS

Assistance is gratefully acknowledge to L. I. Griffin for the original concept of this work, to J. H. Abbott for providing much helpful criticism and analysis, and to R. Grote for assistance with laboratory requirements.

Section VII
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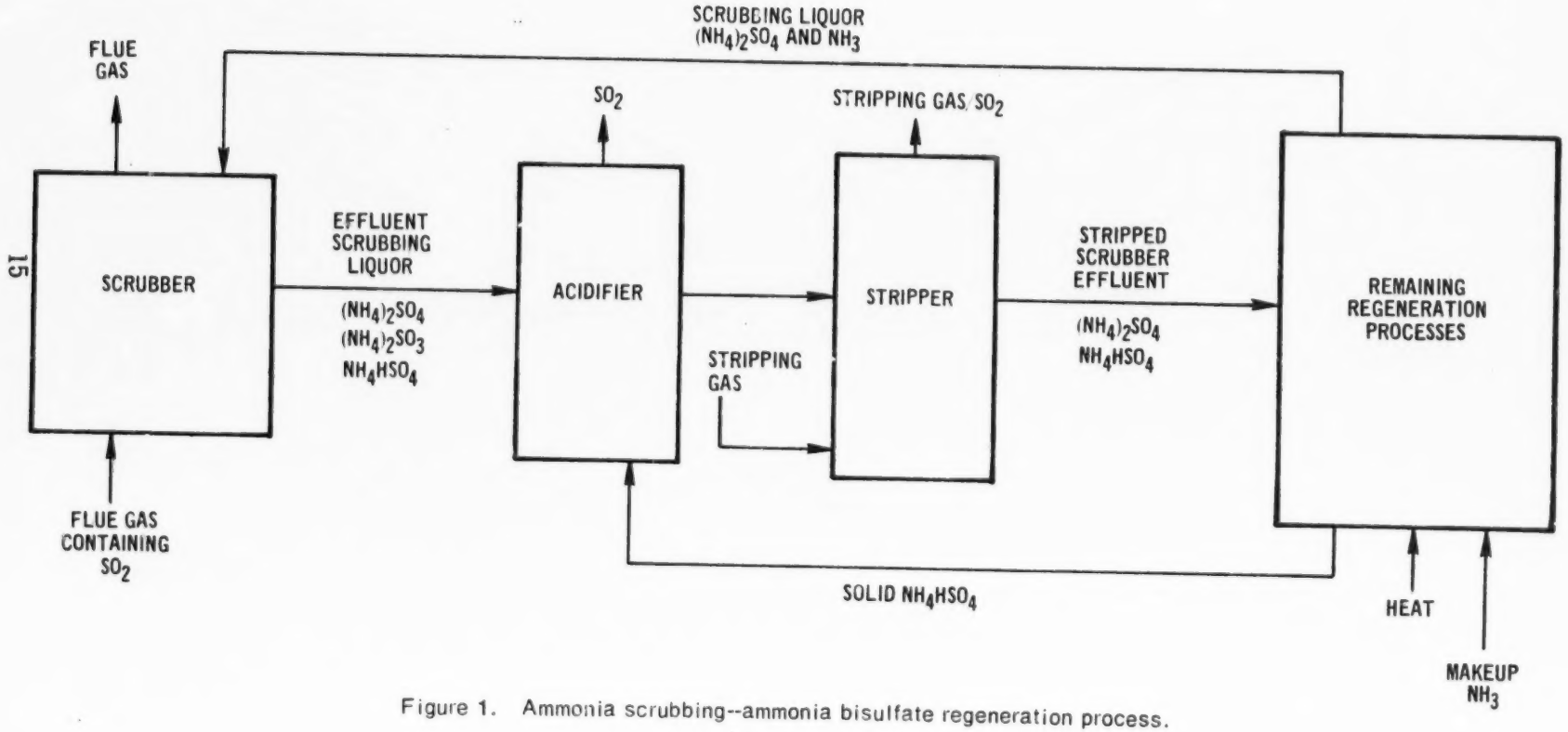

Figure 1. Ammonia scrubbing--ammonia bisulfate regeneration process.

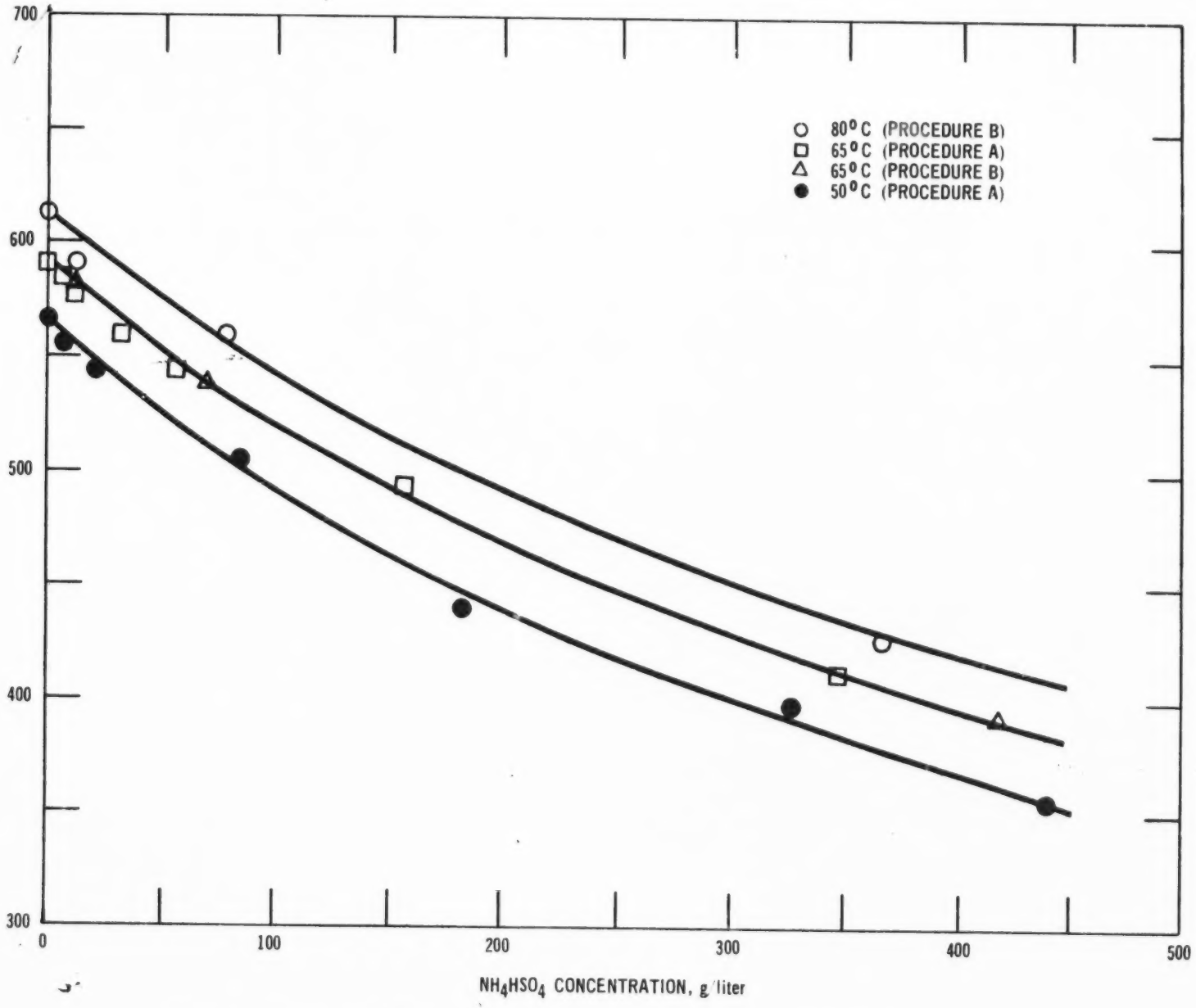

Figure 2. Effect of NH_4HSO_4 on concentration of $(NH_4)_2SO_4$ in a saturated solution.

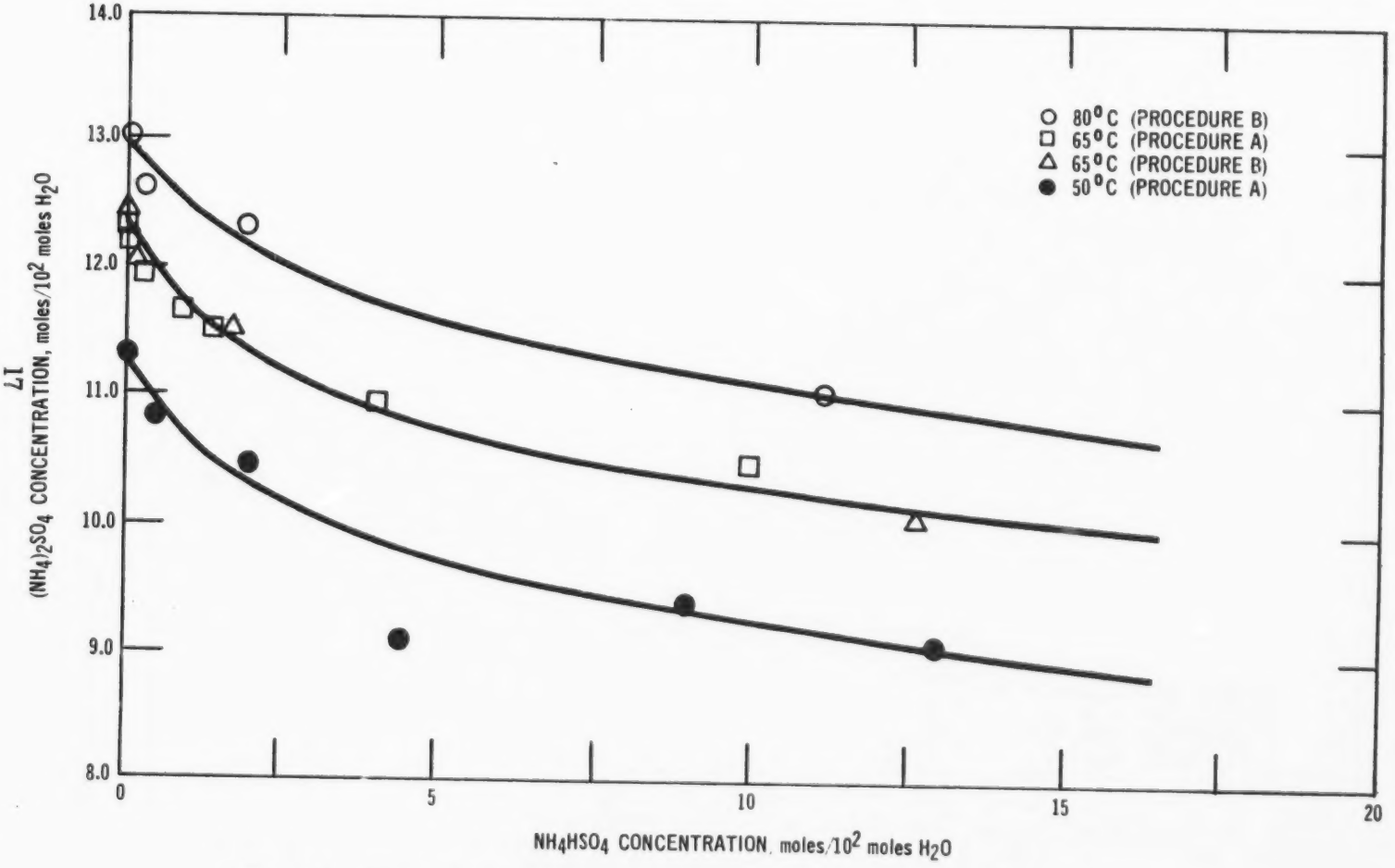

Figure 3. Effect of NH_4HSO_4 on concentration of $(NH_4)_2SO_4$ in a saturated solution.

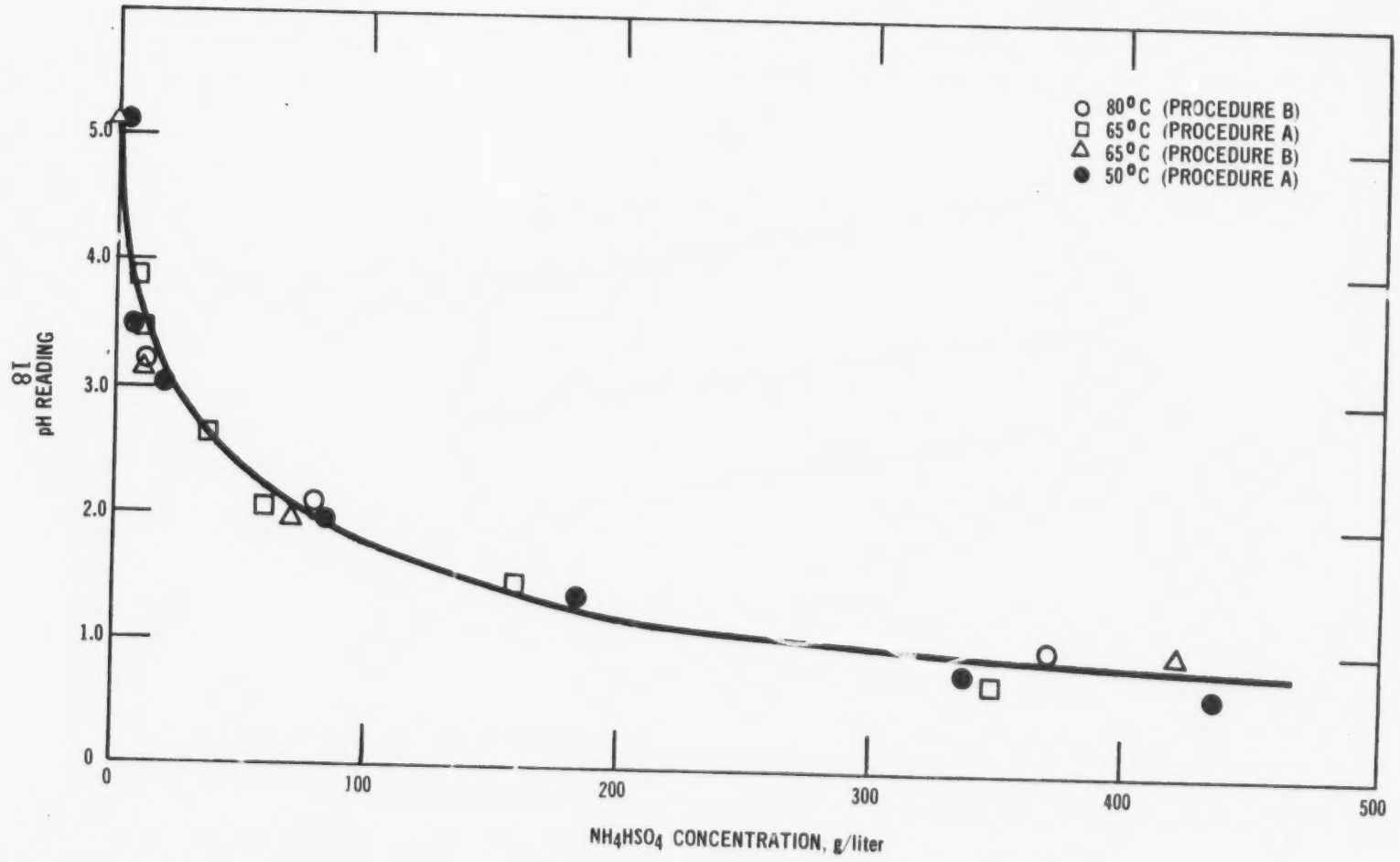

Figure 4. Effect of NH_4HSO_4 on pH reading of a saturated $(NH_4)_2SO_4$ solution.

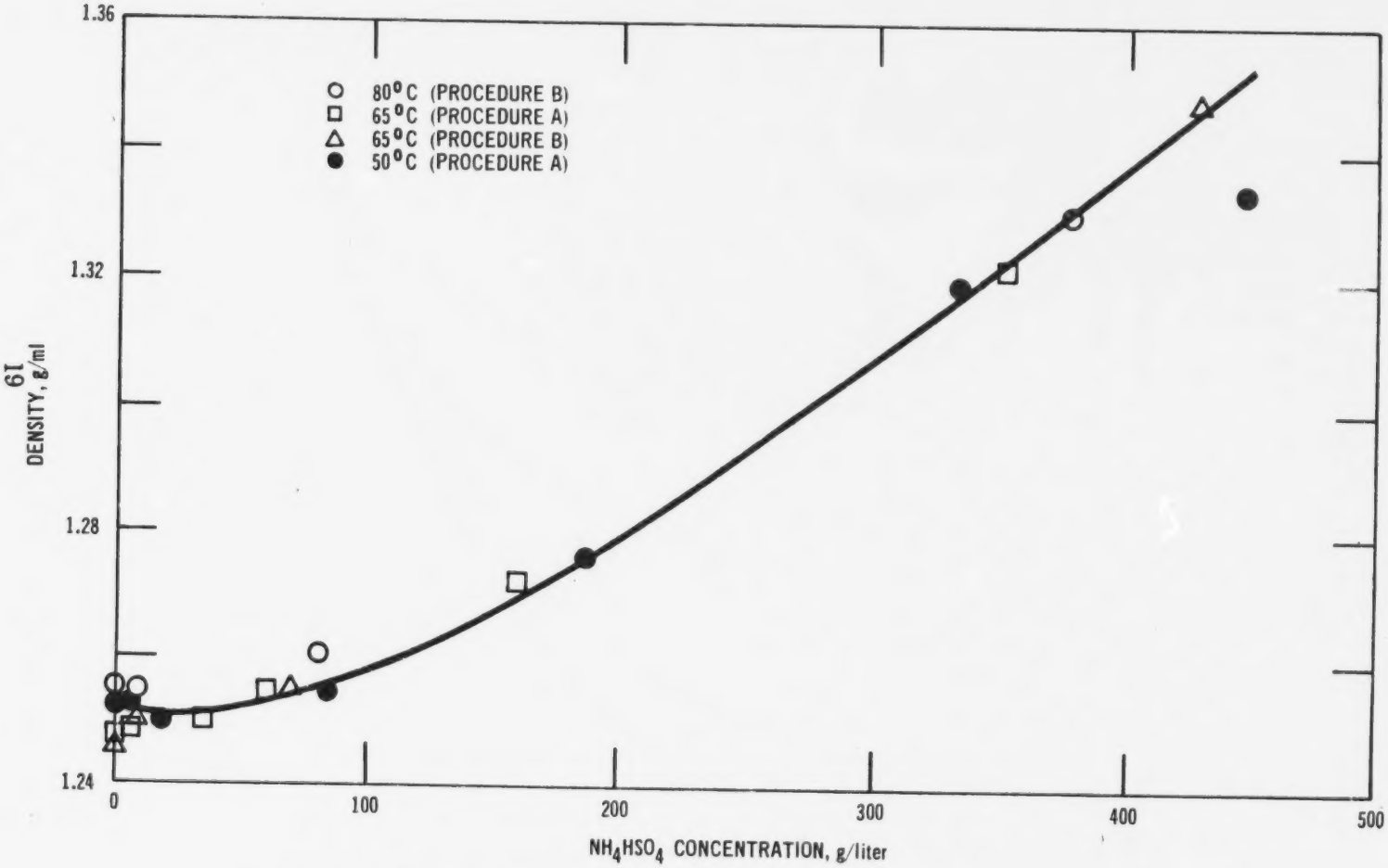

Figure 5. Effect of NH_4HSO_4 on the density of a saturated $(NH_4)_2SO_4$ solution.

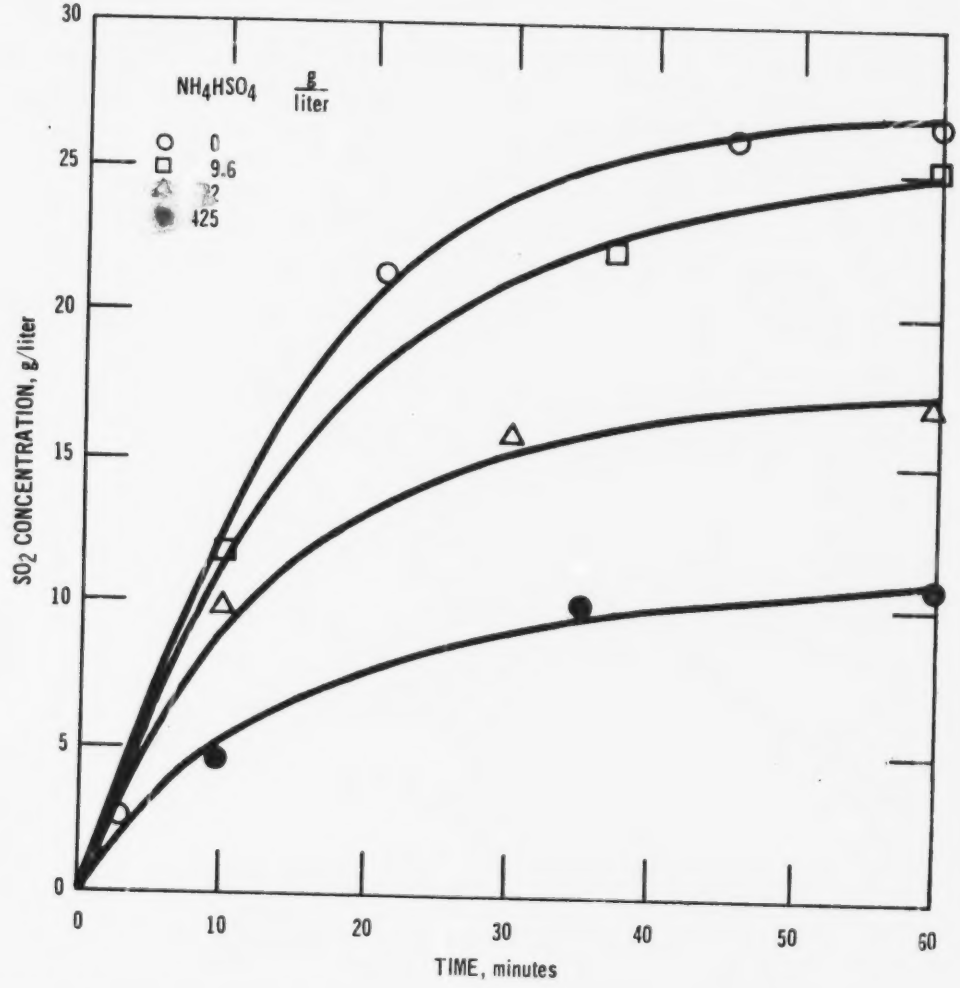

Figure 6. Absorption of SO_2 in saturated $(NH_4)_2SO_4$ solutions containing NH_4HSO_4 at 65° C.

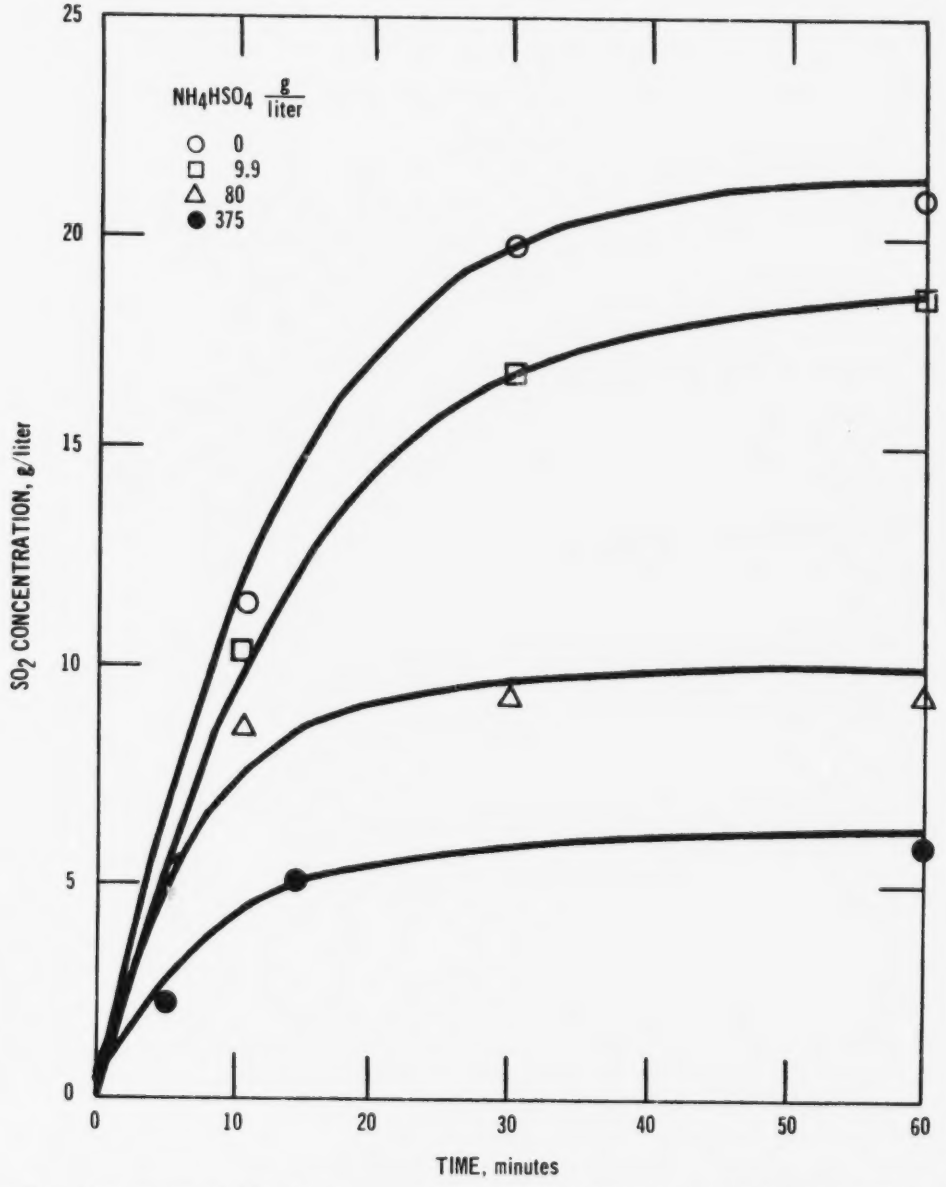

Figure 7. Absorption of SO_2 in saturated $(NH_4)_2SO_4$ solutions containing NH_4HSO_4 at 80° C.

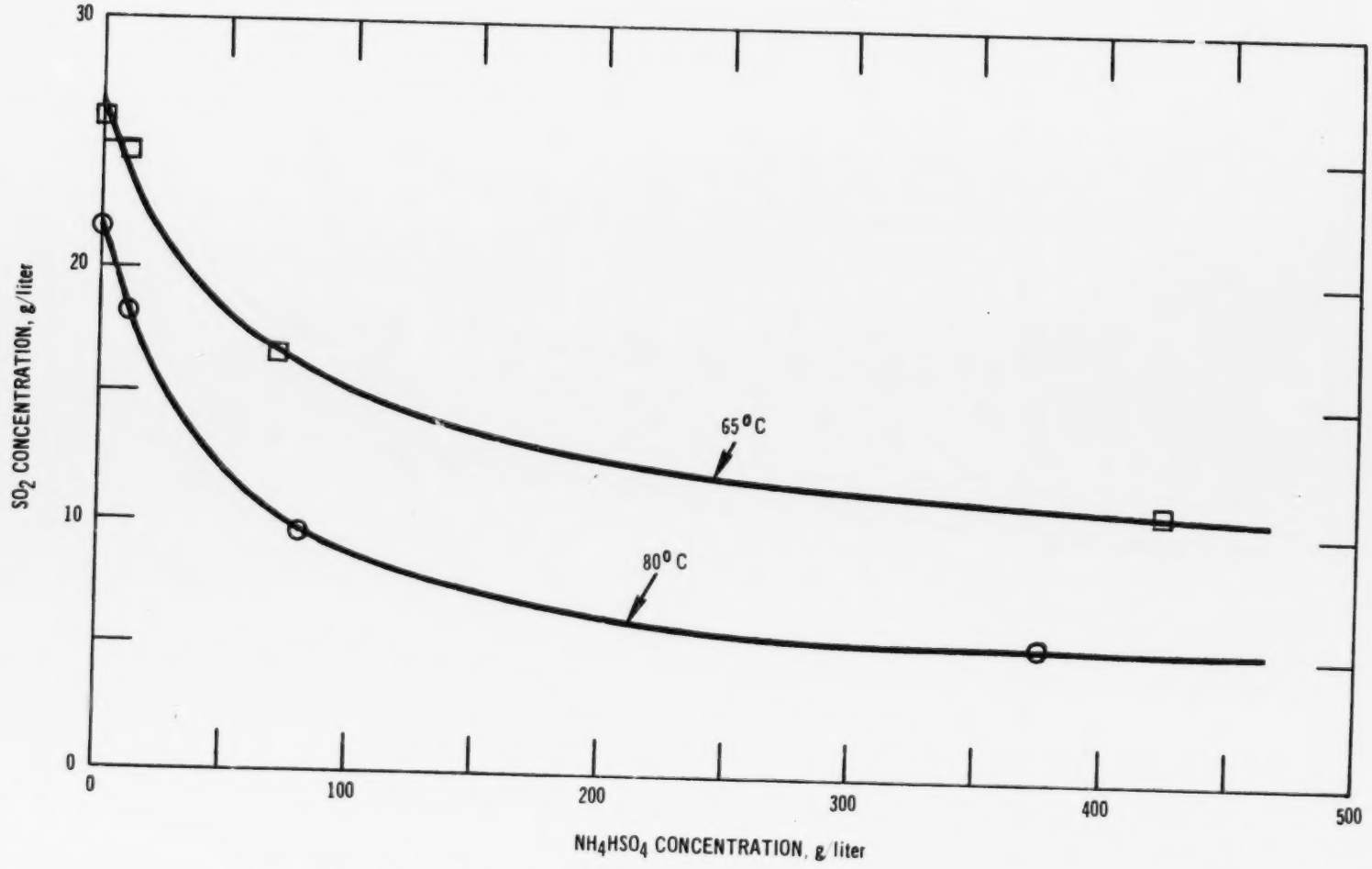

Figure 8. SO_2 solubility in saturated $(NH_4)_2SO_4$ solutions containing NH_4HSO_4.

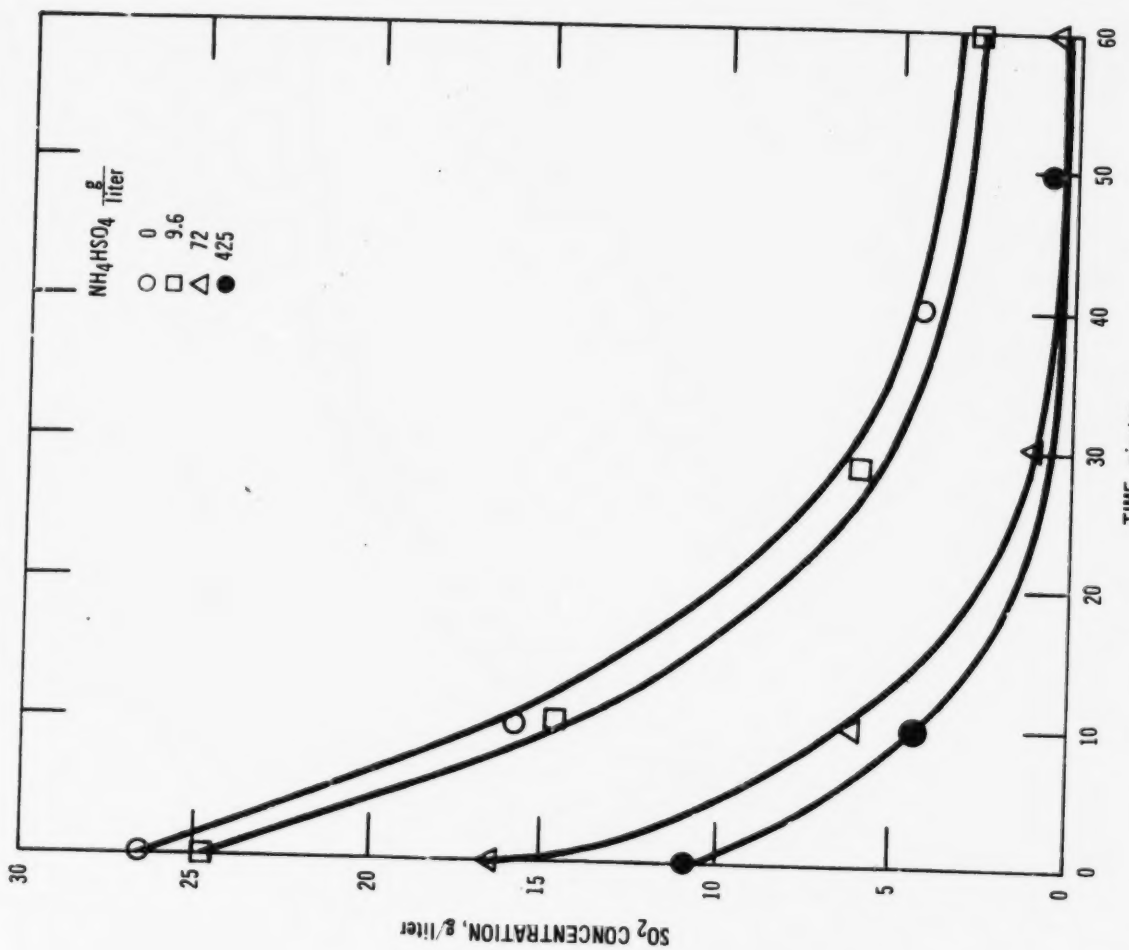

Figure 9. Stripping rates for SO_2 in saturated $(NH_4)_2SO_4$ solutions containing NH_4HSO_4 at 65° C.

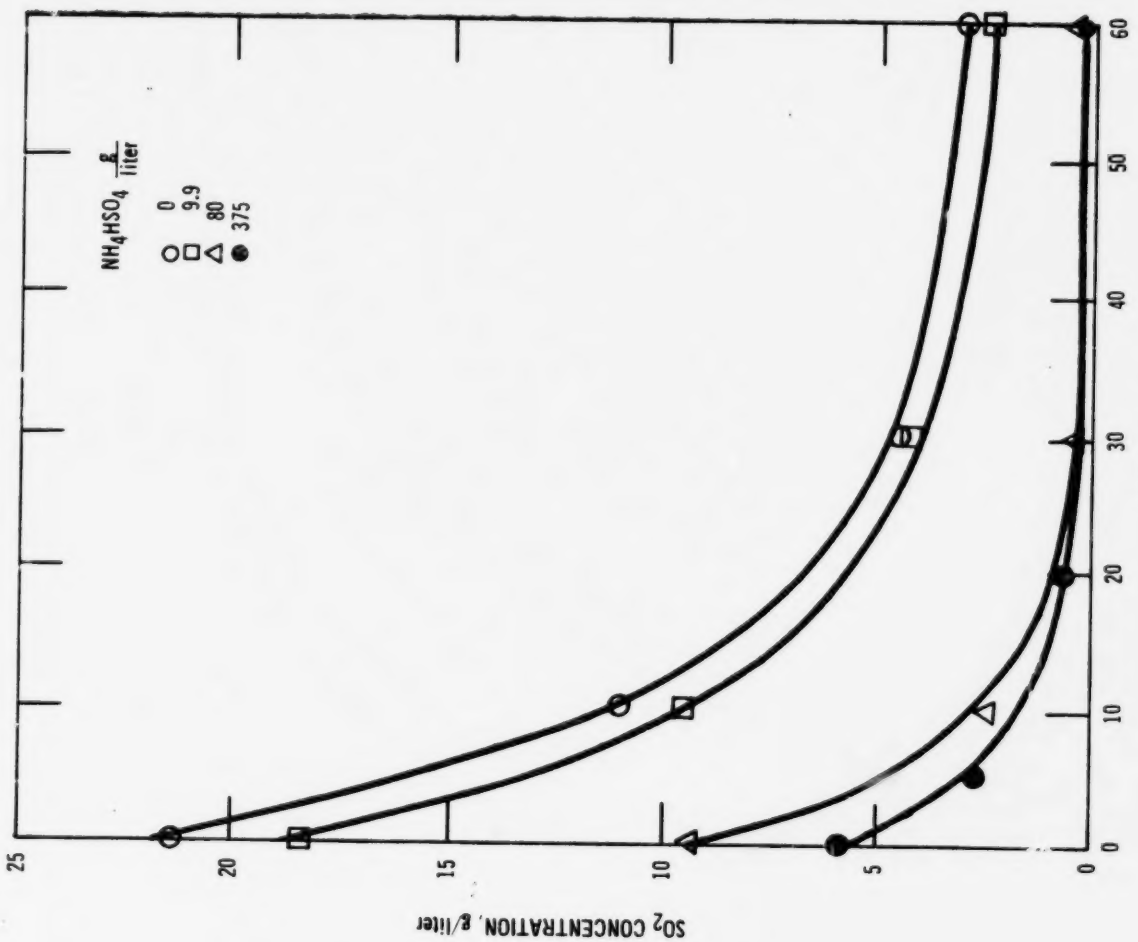

Figure 10. Stripping rates for SO_2 in saturated $(NH_4)_2SO_4$ solutions containing NH_4HSO_4 at 80° C.

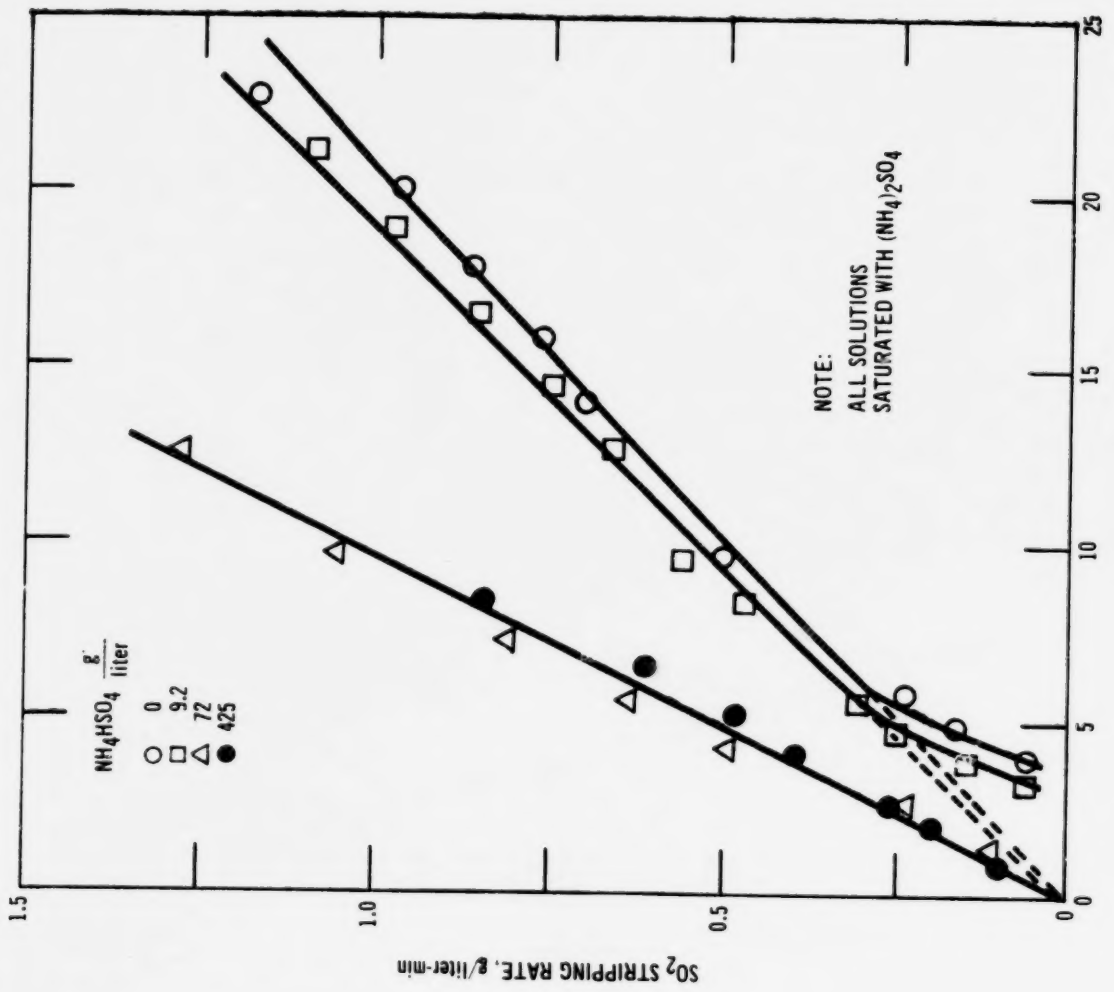

Figure 11. SO_2 stripping as a function of SO_2 concentration at 65 °C.

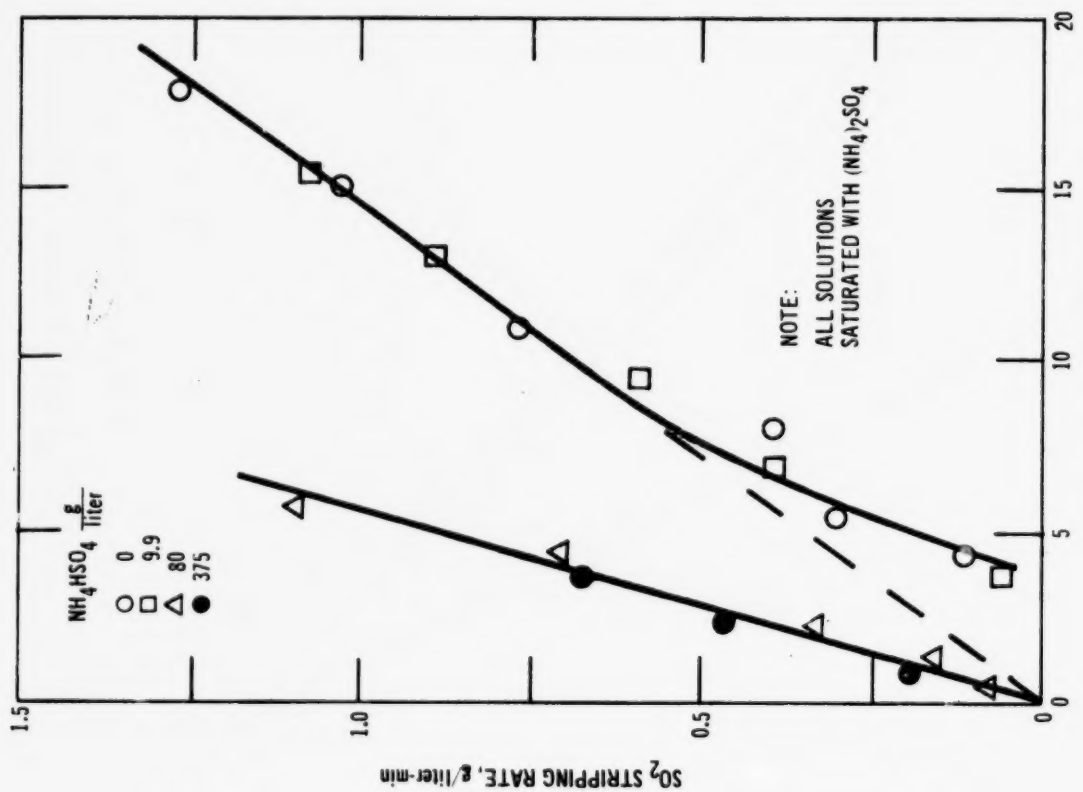

Figure 12. SO_2 stripping as a function of SO_2 concentration at 80° C.

Table 1. DENSITY, pH, AND COMPOSITION OF SATURATED $(NH_4)_2SO_4$ SOLUTIONS AT 50, 65, AND 80°C

Temperature °C	Conc $(NH_4)_2SO_4$		Density g/cm^3	pH Reading
	g/l	moles/100 moles H_2O		
50	570	11.4	1.254	5.18
65	596	12.4	1.251	5.10
80	616	13.1	1.256	5.17

Table 2. EFFECTS OF NH_4HSO_4 ON DENSITY, pH, AND COMPOSITION OF SATURATED $(NH_4)_2SO_4$ SOLUTIONS AT 50, 65, and 80°C

Conc $(NH_4)_2SO_4$		Conc NH_4HSO_4		pH Reading	Density
$\frac{\text{grams}}{\text{liter}}$	$\frac{\text{moles}}{100 \text{ moles } H_2O}$	$\frac{\text{grams}}{\text{liter}}$	$\frac{\text{moles}}{100 \text{ moles } H_2O}$		$\frac{\text{grams}}{cm^3}$
Results at 50°C (Procedure A)					
570	11.4	0	0	5.18	1.254
561	11.1	6	0.14	3.51	1.255
547	10.9	20	0.46	3.05	1.250
509	10.5	85	2.01	2.00	1.255
442	9.2	185	4.37	1.39	1.276
402	9.4	332	8.87	0.82	1.320
358	9.1	441	12.9	0.64	1.334
Results at 65°C (Procedure A)					
596	12.4	0	0	5.10	1.251
500	12.3	5	0.12	3.85	1.248
579	12.0	10	0.24	3.50	1.247
562	11.7	35	0.84	2.66	1.250
548	11.6	60	1.45	2.09	1.255
498	11.0	160	4.07	1.50	1.273
414	10.5	352	9.91	0.74	1.322
Results at 65°C (Procedure B)					
596	12.5	0	0	5.18	1.245
584	12.1	9.6	0.23	3.11	1.251
544	11.6	72.0	1.76	2.00	1.251
394	10.1	425.0	12.55	0.98	1.349
Results at 80°C (Procedure B)					
616	13.1	0	0	5.17	1.255
597	12.7	9.9	0.25	3.11	1.254
565	12.4	80.0	2.0	2.13	1.261
430	11.1	375.0	11.1	1.05	1.331

Table 3. ABSORPTION OF SO_2 IN SATURATED $(NH_4)_2SO_4$ SOLUTIONS CONTAINING NH_4HSO_4 AT 65°C

Time min	pH Reading	Density g/cm^3	SO_2 g/l	$(NH_4)_2SO_4$ g/l	NH_4HSO_4 g/l
		Concentration NH_4HSO_4 = 0 grams/liter			
0	5.18	1.245	0	586	0
3	3.25	1.246	2.5	580	0
21	2.62	1.244	21.2	586	0
45	2.53	1.247	26.0	590	0
60	2.52	1.250	26.4	583	0
		Concentration NH_4HSO_4 = 9.6 grams/liter			
0	3.11	1.251	0	584	9.6
19	2.64	1.250	12.1	582	5.7
35	2.37	1.256	22.6	593	4.5
60	2.31	1.255	24.8	586	3.5
		Concentration NH_4HSO_4 = 72 grams/liter			
0	2.00	1.256	0	544	72.0
10	1.91	1.257	10.2	543	70.0
30	1.87	1.257	15.7	547	63.0
60	1.87	1.260	16.5	554	61.0
		Concentration NH_4HSO_4 = 425 grams/liter			
0	0.98	1.349	0	394	425.0
10	0.95	1.350	4.6	394	418.0
35	0.94	1.352	9.6	391	405.0
60	0.93	1.351	10.9	396	415.0

Table 4. ABSORPTION OF SO_2 IN SATURATED $(NH_4)_2SO_4$ SOLUTIONS CONTAINING NH_4HSO_4 at 80°C

Time min	pH Reading	Density g/cm^3	SO_2 g/l	$(NH_4)_2SO_4$ g/l	NH_4HSO_4 g/l
		Concentration NH_4HSO_4 = 0 grams/liter			
0	5.17	1.255	0	616	0
10	2.91	1.256	11.4	608	0
30	2.68	1.259	19.7	611	0
60	2.66	1.258	21.3	610	0
		Concentration NH_4HSO_4 = 9.9 grams/liter			
0	3.11	1.254	0	585	9.9
10	2.66	1.260	10.3	582	3.7
30	2.54	1.258	16.8	609	11.5
60	2.50	1.259	18.4	598	8.1
		Concentration NH_4HSO_4 = 80 grams/liter			
0	2.13	1.261	0	565	80.0
15	2.10	1.267	8.6	562	76.0
35	2.09	1.266	9.4	564	84.0
55	2.08	1.270	9.4	566	80.0
		Concentration NH_4HSO_4 = 375 grams/liter			
0	1.05	1.331	0	430	375.0
5	1.06	1.329	2.2	436	372.0
15	1.05	1.335	5.0	440	364.0
60	1.04	1.333	5.9	435	382.0

Table 5. STRIPPING RATES FOR SO_2 IN A SATURATED $(NH_4)_2SO_4$ SOLUTION CONTAINING NH_4HSO_4 AT 65°C

Time min	pH Reading	Density g/cm^3	SO_2 g/l	$(NH_4)_2SO_4$ g/l	NH_4HSO_4 g/l
Concentration NH_4HSO_4 = 0 grams/liter					
0	2.52	1.250	26.4	583	0
10	2.70	1.274	15.8	586	0
40	3.10	1.244	4.2	580	0
Concentration NH_4HSO_4 = 9.6 grams/liter					
0	2.31	1.255	24.8	586	3.5
10	2.54	1.253	14.6	582	5.7
28	2.76	1.253	5.8	586	5.7
52	2.94	1.251	3.0	587	3.5
Concentration NH_4HSO_4 = 72 grams/liter					
0	1.87	1.260	16.5	554	61.0
10	1.93	1.258	5.9	547	73.0
30	1.95	1.255	0.9	548	75.0
60	1.97	1.256	0.5	548	70.0
Concentration NH_4HSO_4 = 425 grams/liter					
0	0.93	1.348	10.9	396	415
10	0.95	1.350	4.5	394	420
50	0.96	1.347	0.5	396	430

Table 6. STRIPPING RATES FOR SO_2 IN SATURATED $(NH_4)_2SO_4$ SOLUTIONS CONTAINING NH_4HSO_4 AT 80°C

Time min	pH Reading	Density g/cm^3	SO_2 g/l	$(NH_4)_2SO_4$ g/l	NH_4HSO_4 g/l
Concentration NH_4HSO_4 = 0 grams/liter					
0	2.66	1.258	21.3	610	0
10	2.96	1.258	10.9	610	0
30	3.27	1.255	4.5	613	0
60	3.54	1.255	2.9	611	0
Concentration NH_4HSO_4 = 9.9 grams/liter					
0	2.50	1.259	18.4	598	8.1
10	2.71	1.258	9.5	580	5.3
30	2.86	1.254	4.2	607	11.3
60	2.99	1.254	2.5	600	7.5
Concentration NH_4HSO_4 = 80 grams/liter					
0	2.08	1.270	9.4	566	80.0
10	2.11	1.267	2.3	563	80.0
30	2.12	1.267	0.3	564	86.0
60	2.12	1.267	0.3	568	83.0
Concentration NH_4HSO_4 = 375 grams/liter					
0	1.04	1.351	5.9	435	382.0
5	1.05	1.355	2.6	425	386.0
20	1.06	1.360	0.7	434	372.0
60	1.08	1.359	0.4	430	372.0

Table 7. STRIPPING RATE CONSTANTS

Temperature C°	Conc NH_4HSO_4 g/l	Rate Constant min^{-1}
65	0	0.049
65	9.6	0.053
65	72	0.110
65	425	0.110
80	0	0.070
80	9.9	0.070
80	80	0.180
80	375	0.180

Section VIII
APPENDICES

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Appendix A

LOT ANALYSIS OF CHEMICALS USED

A. Ammonium Sulfate, $(NH_4)_2SO_4$

Manufacturer - Matheson, Coleman, and Bell

Maximum Impurities & Specifications

Arsenic	0.00002%
Chloride	0.0005%
Heavy metals (as Pb)	0.0005%
Insoluble matter	0.005%
Iron	0.0005%
Nitrate	0.001%
pH of a 5% solution	5.0 - 6.0
Phosphate	0.0005%
Residue after ignition	0.005%

B. Ammonium Bisulfate, NH_4HSO_4

Manufacturer - Fisher Scientific Company

Maximum Impurities

Chloride	0.0003%
Iron	0.0004%
Non-volatile matter	0.003%
Other heavy metals (as Pb)	0.001%

Appendix B

THE EFFECTS OF NH_4HSO_4 ON DENSITY, pH, AND COMPOSITION OF SATURATED SOLUTIONS OF $(NH_4)_2SO_4$ AT 80°C USING PROCEDURE A[a]

Conc $(NH_4)_2SO_4$		Conc NH_4HSO_4			Density
grams / liter	moles / 100 moles H_2O	grams / liter	moles / 100 moles H_2O	pH	g/cm^3
Run Number 1					
610	13.0	0	0	4.00	1.249
396	12.6	6	0.15	3.86	1.248
565	11.6	18	0.42	3.55	1.250
530	10.7	44	1.00	2.95	1.252
535	11.44	80	1.96	2.22	1.253
423	9.69	252	6.62	1.50	1.270
Run Number 2					
607	13.0	0	0	4.02	1.250
530	10.6	40	0.92	2.91	1.249
495	9.91	78	1.79	2.61	1.254
366	9.90	407	12.6	1.47	1.277
310	9.05	538	18.0	0.98	1.314

[a]These data are believed incorrect but are included for completeness.